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(54) **DISK DRIVE WITH RECENT WRITE STREAMS LIST FOR DATA REFRESH DETERMINATION**

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CPC ***G06F 11/1456*** (2013.01); *G06F 12/0866* (2013.01); *G11B 15/68* (2013.01); *G11B 17/22* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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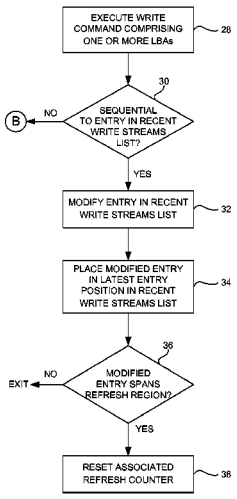
(57) **ABSTRACT**

A disk drive is disclosed comprising a disk comprising a plurality of refresh regions, each refresh region comprising a range of logical block addresses (LBAs). The disk drive further comprises a recent write streams list comprising one or more entries, each entry representing an LBA stream. The disk drive further comprises a head actuated radially over the disk to write data to and read data from the disk, and control circuitry coupled to the head, wherein the control circuitry is operable to execute a write command comprising one or more LBAs, determine whether the one or more LBAs are sequential to an entry in the recent write streams list, modify an entry in the recent write streams list when the one or more LBAs are sequential to the entry, and utilize the modified entry to determine whether to reset a refresh counter associated with a refresh region.

20 Claims, 4 Drawing Sheets



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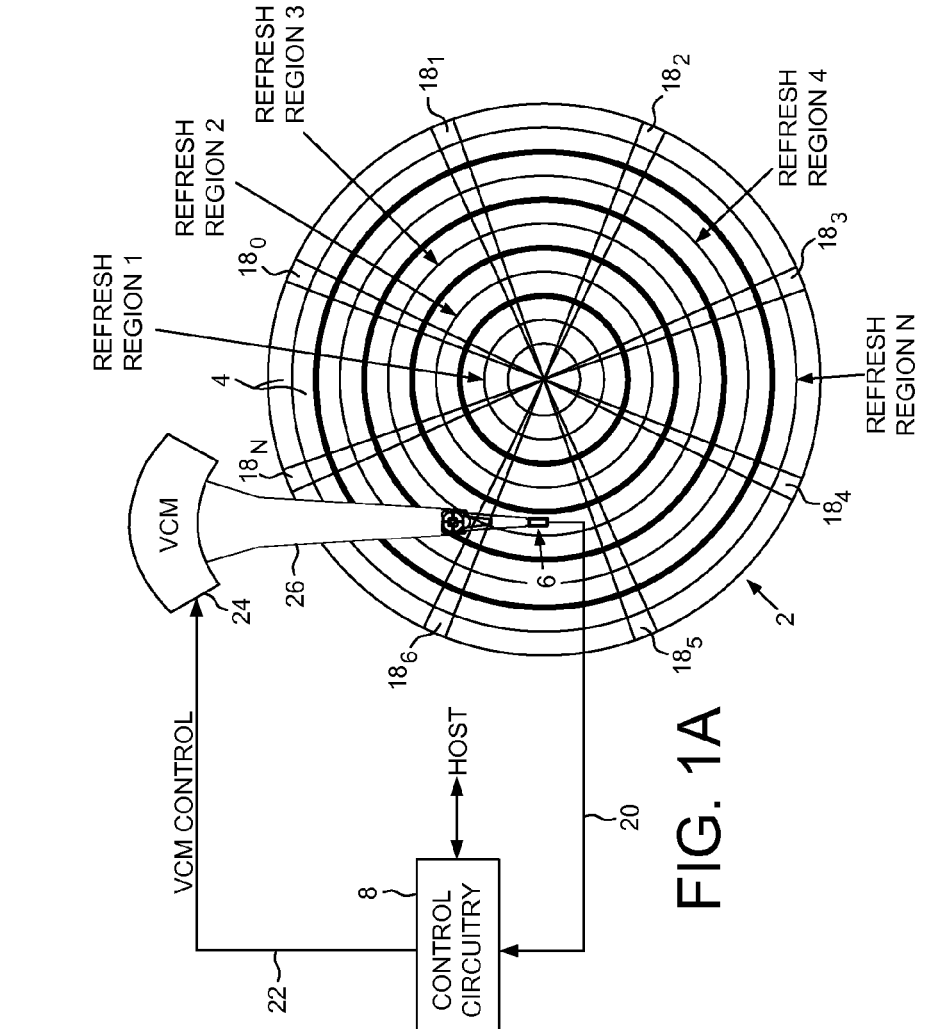
REFRESH REGION 1
REFRESH REGION 2
REFRESH REGION 3
REFRESH REGION 4
REFRESH REGION N
18_0
18_1
18_2
18_3
18_4
18_5
18_6
18_N
4
6
2
VCM
24
26
VCM CONTROL
22
8
CONTROL CIRCUITRY
HOST
20

FIG. 1A

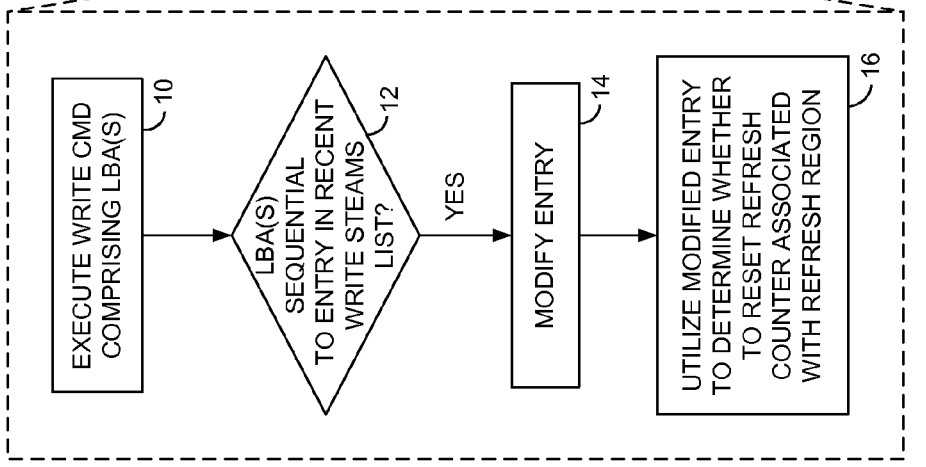
EXECUTE WRITE CMD COMPRISING LBA(S)
10
LBA(S) SEQUENTIAL TO ENTRY IN RECENT WRITE STEAMS LIST?
12
YES
MODIFY ENTRY
14
UTILIZE MODIFIED ENTRY TO DETERMINE WHETHER TO RESET REFRESH COUNTER ASSOCIATED WITH REFRESH REGION
16

FIG. 1B

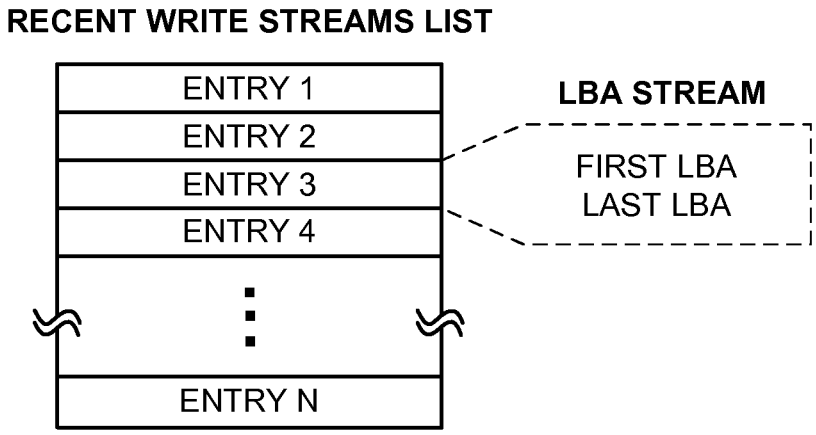
RECENT WRITE STREAMS LIST
ENTRY 1
ENTRY 2
ENTRY 3
ENTRY 4
ENTRY N
LBA STREAM
FIRST LBA
LAST LBA

FIG. 1C

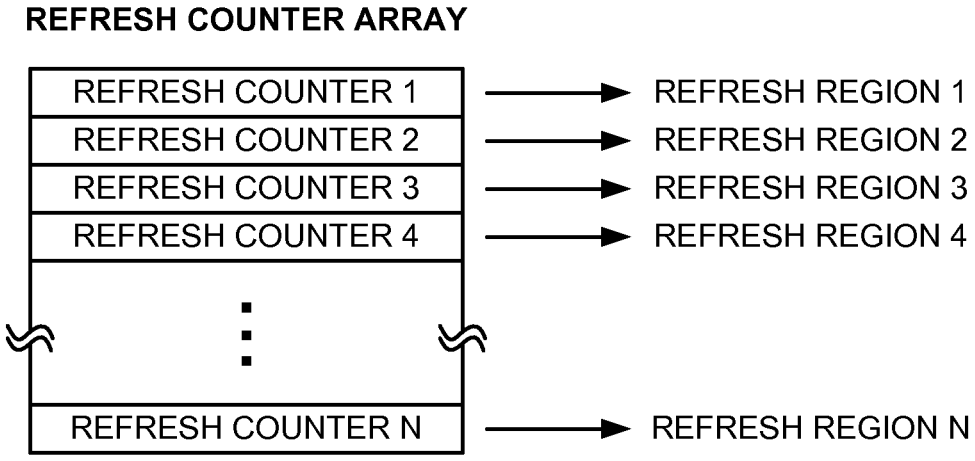
REFRESH COUNTER ARRAY
REFRESH COUNTER 1
REFRESH COUNTER 2
REFRESH COUNTER 3
REFRESH COUNTER 4
REFRESH COUNTER N
REFRESH REGION 1
REFRESH REGION 2
REFRESH REGION 3
REFRESH REGION 4
REFRESH REGION N

FIG. 1D

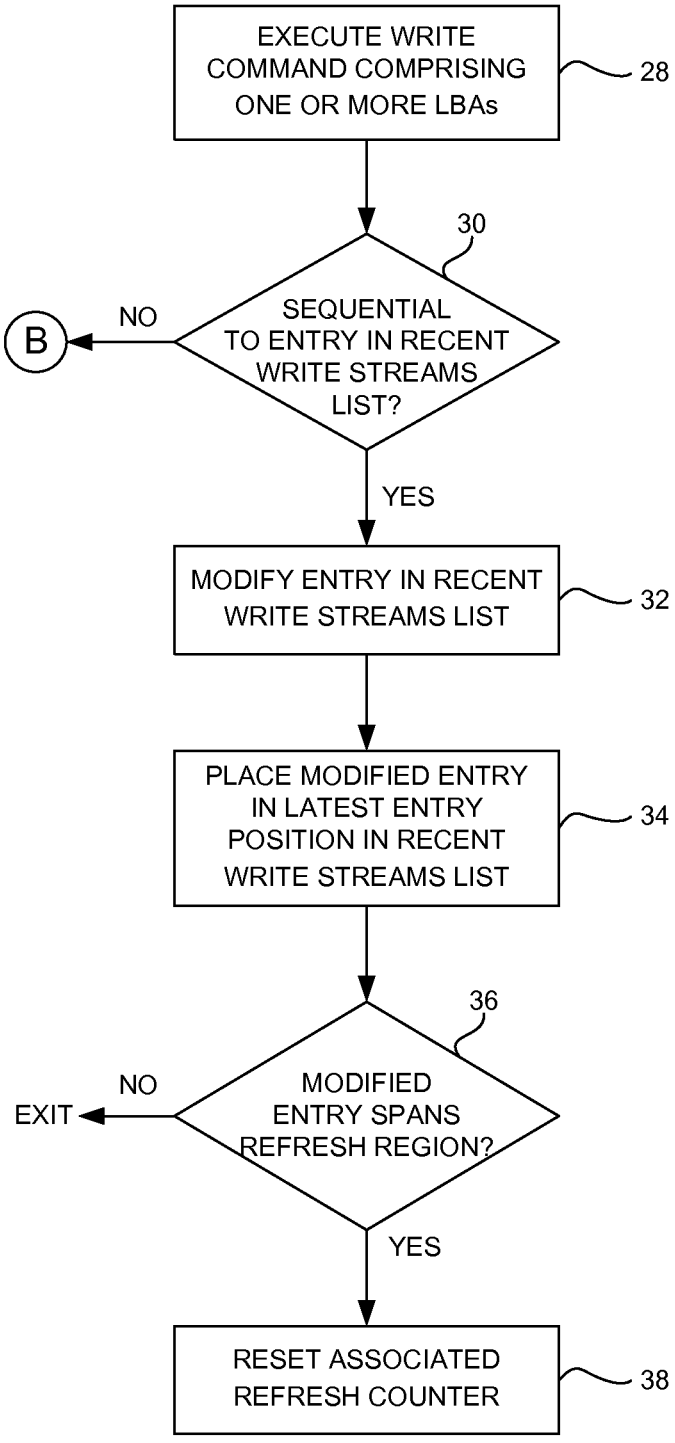
EXECUTE WRITE COMMAND COMPRISING ONE OR MORE LBAs
28
30
SEQUENTIAL TO ENTRY IN RECENT WRITE STREAMS LIST?
NO
B
YES
MODIFY ENTRY IN RECENT WRITE STREAMS LIST
32
PLACE MODIFIED ENTRY IN LATEST ENTRY POSITION IN RECENT WRITE STREAMS LIST
34
36
MODIFIED ENTRY SPANS REFRESH REGION?
NO
EXIT
YES
RESET ASSOCIATED REFRESH COUNTER
38

FIG. 2A

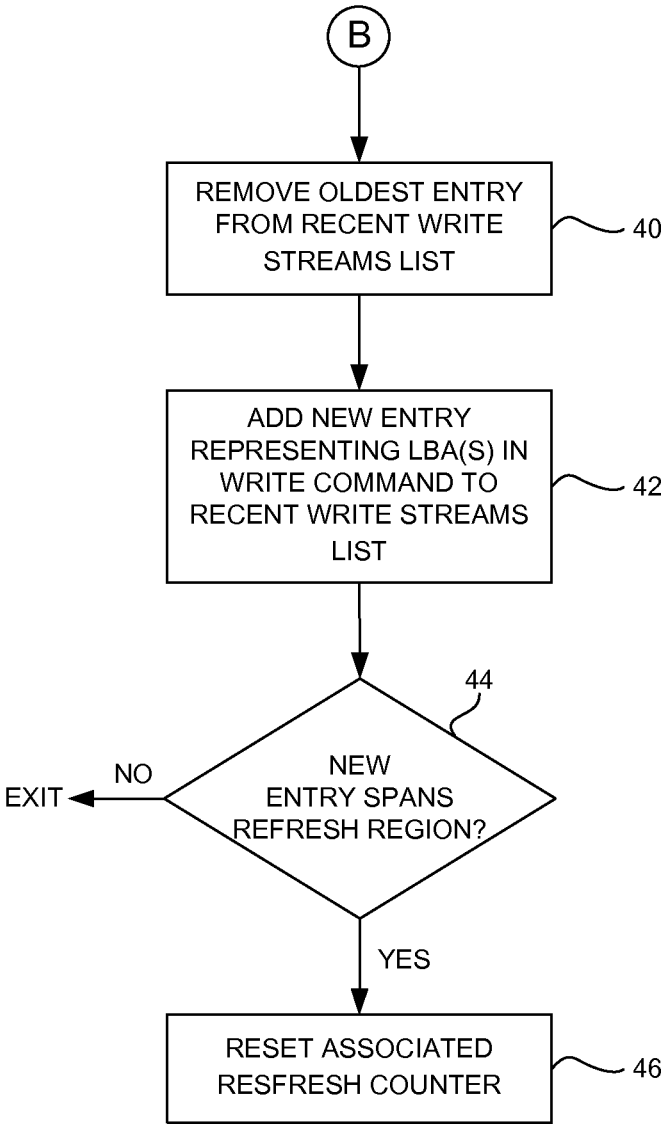
B
REMOVE OLDEST ENTRY FROM RECENT WRITE STREAMS LIST
40
ADD NEW ENTRY REPRESENTING LBA(S) IN WRITE COMMAND TO RECENT WRITE STREAMS LIST
42
44
NEW ENTRY SPANS REFRESH REGION?
NO
EXIT
YES
RESET ASSOCIATED RESFRESH COUNTER
46

FIG. 2B

DISK DRIVE WITH RECENT WRITE STREAMS LIST FOR DATA REFRESH DETERMINATION

BACKGROUND

Disk drives comprise a disk and a head connected to a distal end of an actuator arm which is rotated about a pivot by a voice coil motor (VCM) to position the head radially over the disk. The disk comprises a plurality of radially spaced, concentric tracks for recording user data sectors and embedded servo sectors. The embedded servo sectors comprise head positioning information (e.g., a track address) which is read by the head and processed by a servo control system to control the velocity of the actuator arm as it seeks from track to track.

During a write operation, a current is applied to a write element of the head (e.g., a write coil) to create a magnetic field which magnetizes the surface of the disk by orienting the direction of magnetic grains (e.g., horizontally in longitudinal magnetic recording, or vertically in perpendicular magnetic recording). The orientation of the grains exhibits hysteresis thereby generating their own magnetic field when the write magnetic field is removed. During a read operation, a read element of the head (e.g., a magnetoresistive element) transduces the magnetic field emanating from the disk surface into a read signal that is demodulated into an estimated data sequence.

The hysteresis of the magnetic grains is not permanent meaning that over time the grains will orientate into random directions (magnetic entropy) until the magnetic field is no longer sensed reliably (leading to data errors during reproduction). Magnetic entropy may also be precipitated by various factors, such as increasing ambient temperature. That is, at higher temperatures the uniform alignment of the grains will degrade faster. Another factor that precipitates magnetic entropy is a phenomenon referred to as adjacent track interference (ATI) wherein when writing data to a target track, the fringe field from the write element degrades the uniform alignment of the grains recorded in an adjacent track. The fringe field from the write element may also adversely affect a wider range of tracks with respect to the written track, a phenomena referred to as wide area track erasure or WATER. The degrading effect of ATI on the adjacent tracks as well as WATER on the near adjacent tracks compounds over time with each write operation to the target track. Eventually, the magnetic field emanating from the disk surface will deteriorate to the point that the data is no longer recoverable.

To protect the integrity of data within a region of the disk against degradation over time, the data may be refreshed, wherein the data is read from the disk and rewritten back to the disk. The refresh operation may be performed in the background, for example, after a certain number of writes are made within the region of the disk and/or other regions of the disk located near the region of the disk. The disk drive may perform refresh operations for many regions of the disk in the background to protect the data integrity of the disk.

However, when the disk drive is busy handling host commands, the user may experience an undesirable slow down of the command execution time while the disk drive initiates and executes refresh operations in the background, thereby resulting in an undesirable decrease in drive performance. Thus, it is important to determine when a refresh operation for a particular region of the disk is necessary to avoid the undesirable performance penalty associated with performing a premature refresh operation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows a disk drive according to an embodiment of the present invention comprising a disk comprising a plurality of refresh regions, a head actuated over the disk surface, and control circuitry.

FIG. **1**B is a flow diagram according to an embodiment of the present invention wherein a write command comprising LBA(s) is executed, an entry in a recent write streams list is modified if the LBA(s) in the write command are sequential to the entry, and the modified entry is utilized to determine whether to reset a refresh counter associated with a refresh region of the disk.

FIG. **1**C shows a recent write streams list according to an embodiment of the present invention comprising a plurality of entries, wherein each entry comprises a first and a last LBA of an LBA stream.

FIG. **1**D shows a refresh counter array according to an embodiment of the present invention comprising a plurality of refresh counters, wherein each refresh counter is associated with a refresh region of the disk.

FIG. **2**A is a flow diagram according to an embodiment of the present invention wherein, when LBA(s) in a write command are sequential to an entry in a recent write streams list, the entry is modified, and a refresh counter is reset when the modified entry spans an associated refresh region of the disk.

FIG. **2**B is a flow diagram according to an embodiment of the present invention wherein, when LBA(s) in a write command are not sequential to an entry in a recent write streams list, a new entry associated with the LBA(s) is added to the recent write streams list, and a refresh counter is reset when the new entry spans an associated refresh region of the disk.

DETAILED DESCRIPTION

FIG. **1**A shows a disk drive according to an embodiment of the present invention comprising a disk **2** having a plurality of data tracks **4**, and a head **6** actuated radially over the disk **2** to write data to and read data from the disk **2**. The disk **2** further comprises a plurality of refresh regions, wherein each refresh region comprises one or more of the data tracks **4**, and wherein each data track **4** comprises a plurality of sectors. In one embodiment, each refresh region comprises a pie-shaped group of sectors extending from the inner diameter to the outer diameter of the disk **4**. The disk drive further comprises control circuitry **8** operable to execute the flow diagram of FIG. **1**B, wherein a write command comprising one or more logical block addresses (LBAs) is executed (step **10**), and a determination is made as to whether the one or more LBAs are sequential to an entry in a recent write streams list (step **12**). When the one or more LBAs are sequential to an entry in the recent write streams list, the entry is modified (step **14**). The modified entry is utilized to determine whether to reset a refresh counter associated with one of the refresh regions on the disk (step **16**).

In the embodiment of FIG. **1**A, the disk **2** further comprises a plurality of embedded servo sectors $\mathbf{18}_0$-$\mathbf{18}_N$ which define the plurality of data tracks **4**. Each servo sector **18**, comprises head positioning information such as a track address for coarse positioning during seeks, and servo bursts for fine positioning while tracking the centerline of a target track during write/read operations. The control circuitry **8** processes a read signal **20** emanating from the head **6** to demodulate the servo sectors into a position error signal (PES). The PES is filtered with a suitable compensation filter to generate

a control signal **22** applied to a VCM **24** which rotates an actuator arm **26** about a pivot in a direction that reduces the PES.

Refresh counters are used to determine whether to refresh data stored in the data tracks of the corresponding refresh region of the disk. In one embodiment, when a refresh counter exceeds a threshold, the corresponding refresh region is refreshed in a refresh operation performed by reading and rewriting the data stored in the refresh region. In an embodiment of the invention, when a refresh counter exceeds a lower threshold, the data in the corresponding refresh region is scanned to determine whether a rewrite is necessary, and when a refresh counter exceeds an upper threshold, the data in the corresponding refresh region is rewritten. When the refresh counter exceeds the lower threshold, for example, the data in the corresponding refresh region is rewritten only if a number of detected error correction codes (ECC) errors exceeds an ECC threshold.

The refresh operation may be executed in any suitable manner and at any suitable time. In one embodiment, a refresh operation is performed on a refresh region immediately after its refresh counter exceeds a threshold. In another embodiment, a refresh region is scheduled for refresh after its refresh counter exceeds a threshold, and the refresh operation executed during an idle mode of the disk drive (when the disk drive is not processing access commands received from the host). In one embodiment, the refresh counters are used to prioritize the refresh operations such that refresh regions having higher refresh counters are refreshed sooner relative to the other refresh regions.

In the embodiment of the invention shown in FIG. **1**C, a recent write streams list comprises a plurality of entries, wherein each entry comprises a first and a last LBA of an LBA stream comprising a sequential string of LBAs that have been written to one of the refresh regions of the disk **2**. In the embodiment of FIG. **1**C, the entries in the recent write streams list are ordered from oldest entry to latest entry, wherein the oldest entry (i.e., entry N) is situated in the oldest entry position in the list and the latest entry (i.e., entry **1**) is situated in the latest entry position. In the embodiment of FIG. **1**C, the oldest entry position is located at the bottom of the recent write streams list and the latest entry position is located at the top of the list.

In one embodiment, whenever the control circuitry **8** executes a write command received from the host, the control circuitry **8** updates the recent write streams list by either modifying an existing entry with the LBA(s) in the write command, or adding a new entry representing an LBA stream comprising the LBA(s) in the write command and removing the oldest entry. In an embodiment of the invention, the LBA (s) in the write command are sequential to an entry in the recent write streams list when the LBA(s) are sequential to the LBA stream represented by the entry. In an embodiment, when the LBA(s) in the write command are sequential to an entry, the control circuitry **8** modifies the entry by adding the LBA(s) in the write command to the write stream represented by the entry, wherein the modified entry represents a new write stream comprising the first LBA of the old write stream (the write stream represented by the entry prior to modification) and the last LBA in the write command.

In one embodiment, when the LBA(s) are not sequential to an entry, the control circuitry **8** removes the oldest entry in the recent write streams list, and adds a new entry representing the LBA(s) in the write command, wherein the new entry comprises a first and a last LBA of the write command. In an embodiment, whenever an entry in the recent write streams list is modified, the control circuitry **8** moves the modified entry to the latest entry position in the recent write streams list. In one embodiment, the recent write streams list is stored in volatile memory, such as dynamic random access memory (DRAM) or static random access memory (SDRAM). In an embodiment of the invention, the recent write streams list is stored in non-volatile memory, such as Flash memory or the disk **4**.

In the embodiment of the invention shown in FIG. **1**D, a refresh counter array comprises a plurality of refresh counters, wherein each refresh counter corresponds to one refresh region of the disk **2**. In one embodiment, the control circuitry **8** resets a refresh counter when a new entry or a modified entry spans (i.e., entirely overlaps) the range of LBAs in a corresponding refresh region. A refresh counter may be reset, for example, by setting its count value to zero. In one embodiment, the refresh counter array is implemented by the control circuitry **8**. In an embodiment of the invention, the control circuitry **8** increases a refresh counter whenever data is written in a portion of a corresponding refresh region. In one embodiment, the control circuitry **8** increases the count value of a refresh counter when the control circuitry **8** detects an event that contributes to data degradation in a corresponding refresh region.

FIG. **2**A is a flow diagram executed by the control circuitry **8** according to an embodiment of the present invention, wherein the control circuitry **8** executes a write command comprising one or more LBAs (step **28**). The write command may be executed, for example, by writing data associated with the LBA(s) to one or more data tracks in a refresh region of the disk **2**. The control circuitry **8** determines whether the one or more LBAs in the write command are sequential to an entry in the recent write streams list (step **30**). In one embodiment, the control circuitry **8** determines whether the LBA(s) in the write command are sequential to an entry in the recent write streams list by determining whether the last LBA in one of the entries, when incremented by one, is equal to the first LBA in the write command.

In the embodiment shown in the flow diagram in FIG. **2**A, the control circuitry **8** modifies an entry in the recent write streams list when the LBA(s) in the write command are sequential to the entry (step **32**), and moves the modified entry to the latest entry position in the recent write streams list (step **34**). In one embodiment, the LBA(s) in the write command are sequential to an entry in the recent write streams list when the entry, when incremented by one, is equal to the first LBA in the write command. In an embodiment of the invention, the control circuitry **8** modifies the entry by adding the LBA(s) in the write command to the LBA stream represented by the entry, wherein the modified entry comprises a first LBA of the entry prior to modification, and a last LBA in the write command. In one embodiment, the latest entry position is situated at the top of the recent write streams list and the oldest entry position is situated at the bottom of the recent write streams list.

In the embodiment in FIG. **2**A, the control circuitry **8** determines whether the modified entry spans a refresh region of the disk **2** (step **36**). In one embodiment, the modified entry spans a refresh region when the first and last LBAs in the modified entry encompass the range of LBAs in the refresh region. When the modified entry spans a refresh region, the control circuitry **8** resets an associated refresh counter (step **38**). In one embodiment, the associated refresh counter is reset by setting its count value to zero.

FIG. **2**B is a flow diagram according to an embodiment of the present invention which extends the flow diagram of FIG. **2**A. In the embodiment of FIG. **2**B, when the LBA(s) in the write command are not sequential to an entry in the recent

write streams list, the control circuitry **8** removes the oldest entry from the recent write streams list (step **40**), and adds a new entry in the recent write streams list, wherein the new entry represents an LBA stream comprising the LBA(s) in the write command (step **42**). In one embodiment, the new entry comprises the first and the last LBA in the write command. In an embodiment, when the write command comprises one LBA, the new entry comprises only the single LBA. In one embodiment, the control circuitry **8** places the new entry in the latest entry position in the recent writes streams list. In the embodiment of FIG. **2**B, the control circuitry **8** then determines whether the new entry spans a refresh region of the disk **2** (step **44**). When the new entry spans a refresh region, the control circuitry **8** resets an associated refresh counter (step **46**).

It is noted that the steps in the flow diagrams in FIGS. **2**A and **2**B are shown in a particular order to illustrate respective embodiments of the invention. In other embodiments, the steps in the flow diagrams in FIGS. **2**A and **2**B may be performed in a different order.

Any suitable control circuitry **8** may be employed in the embodiments of the present invention, such as any suitable integrated circuit or circuits. For example, the control circuitry **8** may be implemented within a read channel integrated circuit, or in a component separate from the read channel, such as a disk controller, or certain steps described above may be performed by a read channel and others by a disk controller. In one embodiment, the read channel and disk controller are implemented as separate integrated circuits, and in an alternative embodiment they are fabricated into a single integrated circuit or system on a chip (SOC). In addition, the control circuitry may include a suitable preamp circuit implemented as a separate integrated circuit, integrated into the read channel or disk controller circuit, or integrated into an SOC.

In one embodiment, the control circuitry **8** comprises a microprocessor executing instructions, the instructions being operable to cause the microprocessor to perform the steps of the flow diagrams described herein. The instructions may be stored in any computer-readable medium. In one embodiment, they may be stored on a non-volatile semiconductor memory external to the microprocessor, or integrated with the microprocessor in a SOC. In another embodiment, the instructions are stored on the disk **16** and read into a volatile semiconductor memory when the disk drive is powered on. In yet another embodiment, the control circuitry **8** comprises suitable logic circuitry, such as state machine circuitry.

What is claimed is:

1. A disk drive comprising:

a disk comprising a plurality of refresh regions, each refresh region comprising a range of logical block addresses (LBAs);

a memory separate from the plurality of refresh regions on the disk, the memory storing a recent write streams list comprising one or more entries, each entry representing an LBA stream;

a head actuated radially over the disk to write data to and read data from the disk; and

control circuitry coupled to the head, the control circuitry operable to:

execute a write command comprising one or more LBAs;

determine whether the one or more LBAs in the write command are sequential to an entry in the recent write streams list;

modify an entry in the recent write streams list when the one or more LBAs in the write command are sequential to the entry;

determine whether the modified entry entirely overlaps a refresh region; and

if it is determined that the modified entry entirely overlaps the refresh region, reset an associated refresh counter based on the determination that the modified entry entirely overlaps the refresh region.

2. The disk drive as recited in claim **1**, wherein the control circuitry is further operable to modify the entry by adding the one or more LBAs in the write command to the LBA stream represented by the entry.

3. The disk drive as recited in claim **1**, wherein the control circuitry is further operable to determine that the one or more LBAs in the write command are sequential to the entry in the recent write streams list when a last LBA in the entry, when incremented by one, is equal to a first of the one or more LBAs in the write command.

4. The disk drive as recited in claim **1**, wherein the control circuitry is further operable to add a new entry representing the one or more LBAs in the write command to the recent write streams list when the one or more LBAs are not sequential to an entry in the recent write streams list.

5. The disk drive as recited in claim **4**, wherein the control circuitry is further operable to:

determine whether the new entry entirely overlaps a refresh region; and

reset an associated refresh counter when the new entry entirely overlaps a refresh region.

6. The disk drive as recited in claim **4**, wherein the control circuitry is further operable to remove the oldest entry in the recent write streams list.

7. The disk drive as recited in claim **1**, wherein the control circuitry is further operable to move the modified entry to a latest entry position in the recent write streams list.

8. The disk drive as recited in claim **1**, wherein each refresh region comprises one or more data tracks.

9. The disk drive as recited in claim **1**, wherein the one or more entries in the recent write streams list are ordered from oldest entry to latest entry.

10. The disk drive as recited in claim **1**, wherein each entry in the recent write streams list comprises a first and a last LBA of the LBA stream represented by the entry.

11. A method of operating a disk drive, the disk drive comprising a disk, the disk comprising a plurality of refresh regions, each refresh region comprising a range of logical block addresses (LBAs), a memory separate from the plurality of refresh regions on the disk, the memory storing a recent write streams list comprising one or more entries, each entry representing an LBA stream, and a head actuated radially over the disk to write data to and read data from the disk, the method comprising:

executing a write command comprising one or more LBAs;

determining whether the one or more LBAs in the write command are sequential to an entry in the recent write streams list;

modifying an entry in the recent write streams list when the one or more LBAs in the write command are sequential to the entry;

determining whether the modified entry entirely overlaps a refresh region; and

if it is determined that the modified entry entirely overlaps the refresh region, resetting an associated refresh counter based on the determination that the modified entry entirely overlaps the refresh region.

12. The method as recited in claim 11, further comprising modifying the entry by adding the one or more LBAs in the write command to the write stream represented by the entry.

13. The method as recited in claim 11, wherein determining whether the one or more LBAs in the write command are sequential to an entry in the recent write streams list comprises incrementing a last LBA in the entry by one, and determining that the incremented LBA is equal to a first of the one or more LBAs in the write command.

14. The method as recited in claim 11, further comprising adding a new entry representing the one or more LBAs in the write command to the recent write streams list when the one or more LBAs are not sequential to an entry in the recent write streams list.

15. The method as recited in claim 14, further comprising:

determining whether the new entry entirely overlaps a refresh region; and

resetting an associated refresh counter when the new entry entirely overlaps a refresh region.

16. The method as recited in claim 14, further comprising removing the oldest entry in the recent write streams list.

17. The method as recited in claim 11, further comprising moving the modified entry to a latest entry position in the recent write streams list.

18. The method as recited in claim 11, wherein each refresh region comprises one or more data tracks.

19. The method as recited in claim 11, wherein the one or more entries in the recent write streams list are ordered from oldest entry to latest entry.

20. The method as recited in claim 11, wherein each entry in the recent write streams list comprises a first and a last LBA of the LBA stream represented by the entry.

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